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DRAWINGS ATTACHED

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(54) LAMINATED MAGNETIC CORES FOR ELECTRIC INDUCTION APPARATUS

(71) We, GENERAL ELECTRIC COMPANY, a corporation organised and existing under the laws of the State of New York, United States of America, residing at 1 River Road, Schenectady 12305, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to laminated magnetizable cores for electric induction apparatus.

Large electric power transformers having power ratings of several thousand kilovolt amperes or more and vertical laminated cores weighing several tons present special problems in respect to core strength and rigidity, both during and after assembly. Laminated core legs and yokes, especially those having a high ratio of length-to-weight, are inherently weak mechanically and must be strengthened by securing the laminations firmly together. In large laminated cores designed for operation in a vertical plane, assembly of the coils and final positioning of the top yoke is carried out with the core legs upright. The yoke laminations are solidly clamped between lateral clamping beams while they are still in a horizontal plane after the stacking operation. No additional ties are needed, therefore, to hold the yoke laminations together either in assembly or in operation. The laminated core legs, however, must be made self-supporting in a vertical position for final assembly and must have appreciable self-contained rigidity in operation. While the core legs usually do include lateral clamping plates in final assembly, these clamps must pass through the coil windows and therefore cannot be as massive as the yoke clamps.

According to the present invention in one aspect there is provided a method of manufacturing a magnetizable core weighing five tons or more for electric induction apparatus having a power rating of five KVA or more including the step of forming a stack of ferro-magnetic laminations, said laminations having laterally deformed longitudinal edges presenting therebetween a plurality of lamellar interstices, applying a coating of a thermo-setting resin to a side of the stack at which said longitudinal edges are exposed, some of the resin penetrating said lamellar interstices, and allowing or causing the resin to cure, said coating being of sufficient strength to render said core stack self-supporting when the core is in a vertical position during assembly of such electric induction apparatus.

According to the present invention in another aspect there is provided a magnetizable core weighing five tons or more for electric induction apparatus having a power rating of five KVA or more comprising at least one core leg in the form of a stack of ferro-magnetic laminations, said laminations having laterally deformed longitudinal edges presenting therebetween a plurality of lamellar interstices, and a coating of a cured thermo-setting resin on a side of the stack at which said longitudinal edges would otherwise be exposed, the cured resin of said coating extending into said lamellar interstices, and said coating being of sufficient strength to render the core leg self-supporting when the core is in a vertical position during assembly of such electric induction apparatus.

In carrying out the invention in one preferred embodiment, a large magnetizable core weighing five tons or more and having one or more tall vertical legs is constructed by stacking together in aligned face-to-face relation a plurality of laminations of grain-oriented steel. For large electric power apparatus having a power rating of five KVA or more the core legs may be substantially square or of stepped cruciform shape in cross-section, so that the ratio of the lengths of a pair of mutually perpendicular dimensions of the cross-section of each core leg is of the order of 1:1. Similarly, laminated yoke members are connected in bridging re-

lation across opposite ends of the core legs and connected to the legs by suitable joints. Preferably, the core joints are of the interleaved type.

Each laminated core leg is temporarily bound by a plurality of external steel bands. The core is then erected to set the legs in vertical position and is heated to a temperature between normal room temperature and 200°C, preferably of the order of 150°C. The joint regions at the ends of the core legs are masked, and there is applied to the opposite longitudinal edges of all leg laminations, for a major portion of the leg length, a polymerizable epoxy resin of a type having a thermosetting, e.g., curing, temperature slightly below the temperature of the heated core and having high thermal conductivity after curing. Preferably, the resin is applied by flocking or electrostatic spraying of a "one part" polymerizable resin fusion mixed with a suitable catalyst and stored as a powdered solid. In application, the powdered mixture fuses when deposited on the preheated core and its consequent low viscosity enables it to penetrate the lamellar interstices characteristic of the slightly laterally deformed sheared edges of the steel laminations. The resin is applied to the lamination edges as a thin coating having a thickness of at least 2 mils and preferably of at least 5 mils. Following cooling of the resin, the steel bands are removed and the assembly of the core and coils completed while the core legs remain self-supporting in the vertical position.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawing in which:—

Figure 1 is a side-elevational view of a power transformer core which may embody the present invention;

Figure 2 is an enlarged fragmentary view in perspective of a lower corner of the transformer core showing a portion of the lower yoke and a portion of one vertical leg;

Figure 3 is a view similar to that of Figure 2 showing a single core leg and yoke erected in vertical position and prepared for edge bonding of laminations prior to final assembly, and

Figure 4 is an enlarged cross-sectional view of several core laminations edge bonded by thermosetting epoxy resin applied in accordance with the invention.

Referring now to the drawing, and particularly to Fig. 1, there is shown a transformer core assembly having a plurality of vertical legs 2 and lower and upper yoke members 3, 3[1], respectively, bridged across opposite ends of the legs 2. The core legs 2 and yoke members 3 and 3[1] are each formed of a plurality of flat laminations 4 of magnetizable steel. A pair of flat clamping plates 5, drawn together by a plurality of bolts 5[1], securely clamp together the laminations of each core leg 2. The laminations of the upper and lower core yokes 3 and 3[1] are clamped together between pairs of clamping beams 6, 6[1] which extend along and beyond the ends of each core yoke. Preferably the joints between the core legs 2 and the yokes 3, 3[1] are cut and interleaved as illustrated in U.S. Patent No. 3,212,042-Twomey.

As shown at Fig. 2, the core legs 2 are of cruciform configuration constituted by a central stack of wide laminations and one or more outer stacks of narrower laminations assembled in progressively narrowing stepped relation. Each group or stack of laminations of equal width is assembled with the laminations in face-to-face relation and their longitudinal edges in alignment. If desired, of course, all the laminations of each core leg may be identical in width so that the leg of cross-section is rectangular, or the number of stepped variations in lamination width may be sufficiently large that the core leg cross-section approximates a circle. Whether cruciform or rectangular, it is preferable that the perpendicular cross-sectional dimensions of each core leg be approximately equal in length, i.e., in the ratio of nearly 1:1, thereby favorably to utilize the circular axial aperture or window of a circular coil surrounding the leg. Preferably, also, the laminations 4 are stamped out of grain-oriented silicon steel having a magnetic direction coincident with the lengthwise dimension of each lamination. If desired, each core leg may be made up of two similar and oppositely disposed sets of laminations centrally spaced apart to form a transverse slot as illustrated in Fig. 2 of U.S. Patent No. 2,920,296-Neurath.

In power transformers having ratings of the order of 5 to 35 KVA or more, the core assembly is massive and commonly has a weight of the order of 5 to 20 tons or more. The core legs are ordinarily quite long in relation to their cross-sectional dimensions and have little resistance to lateral deformation or bending unless the laminations are firmly clamped or bound together. In the assembly operation, therefore, it is necessary to stiffen the core legs independently of the clamping plates 5 before they are set in an upright position for final assembly. It is desirable that the binding means used to tie leg laminations together prior to assembly of the clamping plates 5 apply a substantially uniform binding force throughout the length of each leg and thus avoid the uneven distribution of stress imposed by spaced-apart bolts or straps. It is to be noted that in the final application of clamping plates 5, the plates serve to distribute the stress of bolts 5.

To render the leg laminations self-supporting without the creation of high local stresses, a thin coating of thermosetting epoxy resin is applied to the longitudinal edge surfaces of the leg laminations along substantially the full length of each leg. The coating is applied to a thickness in the range from 2 to 50 mils, preferably 5 mils, and constitutes the sole means for rendering the laminations of each leg self-supporting in the vertical position to final assembly of the outer clamping plates 5. The mode of application of the resin binder and the resulting self-supporting structure of each core leg will be more fully understood from the following detailed description of a typical core lay-up and assembly operation.

The laminations 4 are cut to size by a slitting and shearing operation well known to those skilled in the art, and as a consequence the edges, and particularly the longitudinal major edges, of the laminations are slightly laterally deformed as illustrated in the enlarged cross-section at Fig. 4. The laminations are initially stacked together in horizontal position with the legs and at least the lower yoke member interfitted in their final relative positions. If desired, the upper yoke member may also be interfitted with the legs during the lay-up operation, but the upper yoke if so fitted, must be later removed to place the coils on the core, as is well known to those skilled in the art. When the lay-up is completed in the horizontal position, the clamping beams 6, 6^1 are placed on opposite sides of each yoke 3, 3^1, and the yoke laminations thus firmly clamped together. While still in this horizontal position the laminations of each core leg 2 are temporarily bound together by means of a plurality of external steel straps or bands 8, as illustrated at Fig. 3. The partially assembled core is then set upright with the legs 2 in vertical position, the leg laminations being restrained from collapse only by the temporary steel bands 8.

With the core in upright position, it is placed in a suitable oven and heated to a temperature of the order of 150°C in preparation for application of a thin coating of thermosetting resin to the longitudinal major edges of all leg laminations. Such a coating is illustrated at Figs. 3 and 4 and designated by the reference numeral 10. For large transformer cores having legs of the order of 5 feet or more in height and a cross-sectional area of 1 to 3 square feet, it has been found sufficient to provide a coating of at least 2 mils, preferably at least 5 mils, and preferably no more than about 50 mils in thickness. Coating 10 is applied to the preheated core in powdered or partially melted form, preferably by electrostatic spraying or by flocking, as through a nozzle 11 illustrated at Fig. 3. As illustrated at Fig. 4, the laminations 4 are deformed laterally at their edges as a result of the shearing operation, and thus when stacked together, form between adjacent laminations a plurality of shallow lamellar interstices 12 which the material of the coating 10 penetrates under high temperature conditions, thereby to give added strength to the bonded assembly. After spraying or flocking is completed the core is allowed to cool and the straps 8 removed after the resin has cured.

While the techniques of electrostatic spraying or flocking have been found preferable, it will be understood by those skilled in the art that the powdered resin may also be applied by other known methods, such as flame spraying, or sprinkling or in an aerated or fluidized bed.

The coating 10 of resinous edge bonding material must have high tensile strength and good adhesion to the laminations at their edges and in the interstices 12. To preclude undesired interference with cooling of the core in operation, the coating should be as thin as possible and should have a high degree of thermal conductivity. Preferably, its termal conductivity should be approximately the same as the immediately adjacent layer of air or dielectric fluid in which the core is immersed.

The material of the coating 10 should also be sufficiently low in viscosity when heated to fusing or melting condition that it will fully penetrate the interstices 12 and still be sufficiently high in viscosity that it will adhere without running off the vertical surface. Finally, the resinous coating must be formed of a material initially thermoplastic so that it can be melted or fused in application (i.e., prior to or after deposition on the core) and also polymerizable, i.e., thermosetting, when reacted with a suitable catalyst. The thermosetting or cuting temperature should be sufficiently low that it will not damage other conventional parts of the core such as wood-spacing blocks, and the like, it should be sufficiently high that the mixture will not react at room temperature.

We found that a "one-part" compound comprising a solid monomer, melt fusion mixed with a heat reactive latent hardener and subsequently powdered, is especially suitable for application by electrostatic spraying or flocking. Such a one-part compound when elevated to the activation temperature of the latent hardener reacts by polymerization to form a strong thermoset coating. A compound we have found particularly suited for this purpose is known commercially as XR5149 and is manufactured and sold by Minnesota Mining and Manufacturing Company. In general, it is believed that any epoxy compound comprising a diglycidyl ether of bisphenol A, characterized by reactive epoxy or ethoxylene groups and a

temperature active hardening agent will possess the unique combination of qualities required to meet the severe edge-bonding requirements in large, heavy magnetizable cores of the characterter described.

In practice we have utilized the epoxy resin XR5149 to edge bond the leg laminations of several large transformer cores having vertical legs of the order of six feet in height and fifteen inches in diameter, the leg cross-section being made substantially circular by step variation of lamination widths. In all cases we have obtained excellent results in respect of beam strength and rigidity of the legs, heat-dissipation characteristics and reduction of electrical core loss and noise.

WHAT WE CLAIM IS:—

1. A method of manufacturing a magnetizable core weighing five tons or more for electric induction apparatus having a power rating of five KVA or more including the step of forming a stack of ferro-magnetic laminations, said laminations having laterally deformed longitudinal edges presenting therebetween a plurality of lamellar interstices, applying a coating of a thermo-setting resin to a side of the stack at which said longitudinal edges are exposed, some of the resin penetrating said lamellar interstices, and allowing or causing the resin to cure, said coating being of sufficient strength to render said core stack self-supporting when the core is in a vertical position during assembly of such electric induction apparatus.

2. A method as claimed in Claim 1 wherein the thickness of the cured coating lies in the range of from 2 to 50 mils.

3. A method as claimed in Claim 1 or Claim 2 including the steps of strapping the laminations to restrain collapse of the stack before applying said coating, and removing the strapping after the resin is cured.

4. A method as claimed in any one of Claims 1 to 3 including the step of heating the stack to a temperature above the curing temperature of the resin before applying said coating, the coating being applied while the stack temperature is above curing temperature, and then allowing the resin to cure by permitting the stack to cool.

5. A method as claimed in Claim 4 wherein the curing temperature of said resin is between normal room temperature and 200°C.

6. A method as claimed in any one of Claims 1 to 3 wherein said coating is applied by depositing a powdered solid thermo-setting resin mixture of a thermo-plastic, thermo-settable resin and a solid curing catalyst under such temperature conditions as to cause the resin mixture to fuse and some of it to penetrate said interstices before the resin mixture cures.

7. A method as claimed in Claim 6, wherein the stack is preheated to a temperature above the fusing temperature of said mixture before said deposition.

8. A magnetizable core weighing five tons or more for electric induction apparatus having a power rating of five KVA or more comprising at least one core leg in the form of a stack of ferro-magnetic laminations, said laminations having laterally deformed longitudinal edges presenting therebetween a plurality of lamellar interstices, and a coating of a cured thermo-setting resin on a side of the stack at which said longitudinal edges would otherwise be exposed, the cured resin of said coating extending into said lamellar interstices, and said coating being of sufficient strength to render the core leg self-supporting when the core is in a vertical position during assembly of such electric induction apparatus.

9. A core as claimed in Claim 8 wherein the thickness of said coating lies in the range of from 2 to 50 mils.

10. A core as claimed in Claim 8 or Claim 9 wherein the ratio of the lengths of a pair of mutually perpendicular dimensions of the cross-section of said core leg is substantially unity.

11. A core as claimed in any one of Claims 8 to 10 wherein the laminations are formed of grain oriented steel.

12. A core substantially as described herein with reference to the accompanying drawings.

13. A method of manufacturing a core as claimed in Claim 1 and substantially as described herein with reference to the accompanying drawings.

14. A magnetizable core when made by a method as claimed in any one of Claims 1 to 7 or 13.

15. Electric induction apparatus comprising a core, as claimed in any one of Claims 8 to 12 or 14.

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1326766 COMPLETE SPECIFICATION

1 SHEET This drawing is a reproduction of the Original on a reduced scale

Fig.1.

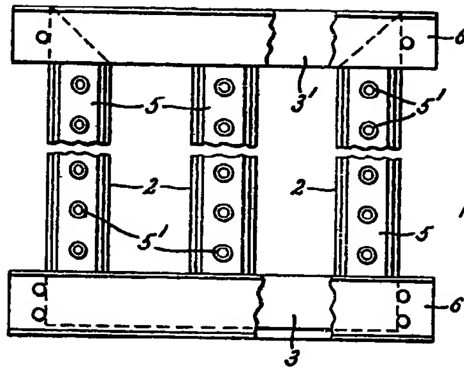

Fig.4.

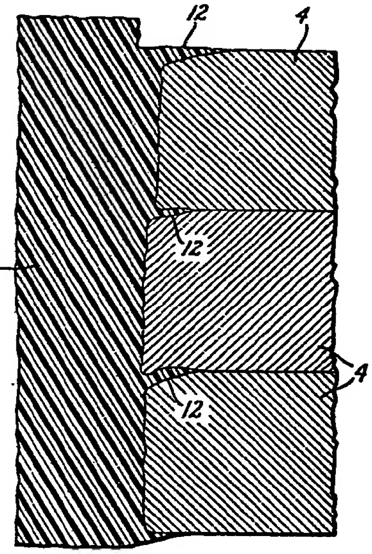

Fig.3.

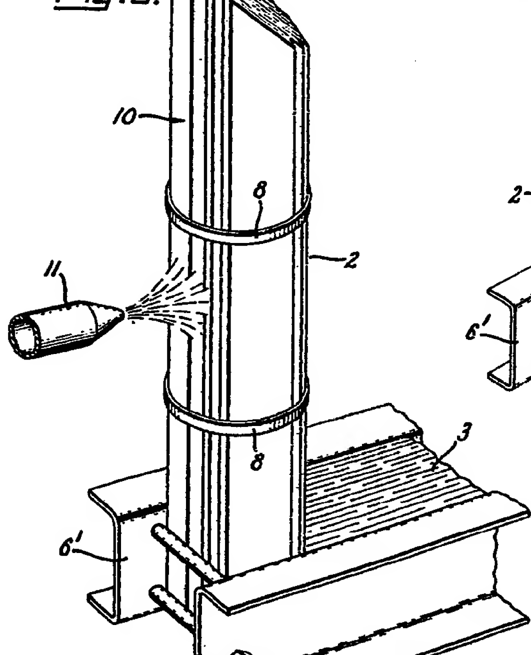

Fig.2.